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Range Instrumentation Development

P. H. Dugger
Calspan Field Services, Inc.

July 1982

Final Report for Period 1 October 1979 – 30 September 1980

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ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This report has been reviewed and approved.

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FOR THE COMMANDER

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MARION L. LASTER
Director of Technology
Deputy for Operations

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Technology work during FY80 resulted in improved instrumentation capabilities for the VKF aeroballistic ranges: an experimental high-speed pyrometry system employing an indium-antimonide infrared detector has demonstrated a capability for in-flight nosetip surface temperature measurements at levels as low as 600 K. The use of narrow bandpass (30 Å) optical filters in laser photography systems was found to improve photographic quality during

20. ABSTRACT, Concluded.

applications where background luminosity was deleteriously intense. A time-resolved spectrometer that covers the wavelength band from 3500 to 6800 Å was designed to facilitate the spectral characterization of hypervelocity impact phenomena. A noninterfering model detection system that uses a continuous-wave X-ray source and a scintillation detector was designed and fabricated. Evaluations showed that the system is impervious to high background luminosity levels and that it will provide reliable trigger pulses in range areas where such conditions exist. A high-intensity light source with fast rise time (10 μsec) and adjustable pulse duration (40 to 625 μsec) was procured to facilitate applications of a Beckman & Whitley high-speed framing camera for hypervelocity impact studies.

PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC). The results presented were obtained by Calspan Field Services, Inc., AEDC Division, operating contractor for the Aerospace Flight Dynamics Testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee, under AEDC Project Number V32L-32. The Air Force project manager was Mr. Marshall Kingery, AEDC/DOT. The manuscript was submitted for publication on September 30, 1981.

The research was conducted in the AEDC von Kármán Gas Dynamics Facility. The author, P. H. Dugger, was project engineer. Other members of the project team and the areas of experimental work for which they were responsible were as follows: C. P. Enis - infrared pyrometry systems; J. W. Hill - laser photography improvements; E. D. Tidwell - time-resolved spectrometer; R. C. Hensley and H. G. Harris - cw X-ray detector system; and L. E. Simpson - variable duration light source.

The author wishes to thank Mr. R. E. Hendrix, Supervisor, Range Instrumentation Section, VKF, for his guidance and suggestions throughout the program and for his critical review of the final manuscript.

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1.0 INTRODUCTION

In order to ensure against obsolescence of the aeroballistic ranges of the von Kármán Gas Dynamics Facility (VKF) as practical ground test facilities, it is essential to develop and expand instrumentation system capabilities to meet the imposed data acquisition requirements as areas or methods of testing change or become more sophisticated. Experimental research programs for this express purpose have been in effect for the past ten years. The results from some of these past projects are presented in Refs. 1 through 3. The purpose of this report is to describe designs, developments, improvements, and evaluations of instrumentation systems carried out under the most recent of these technology projects.

2.0 PYROMETER DEVELOPMENT

Several areas of testing in Track G require measurement of nosetip surface temperatures at temperature levels considerably lower than the 1250-K lower measurement limit of routinely used photographic pyrometry systems (Refs. 1 through 5). In the photopyrometry technique, a special camera, incorporating an image intensifier device, views the in-flight model at an angle 5 deg from head-on and records a self-luminosity photograph of the nosetip; this photograph is subsequently converted to temperature information through comparisons with photographs of known-temperature sources. A resultant isothermal contour map is shown in Fig. 1. The central portion of this contour map represents the front surface of the nosetip. (A side-view laser photograph of the particular test model is shown in Fig. 2.) Contour intervals are 100 K; the heavier lines are 2000 K, and the others are 1900-, 1800-, and 1700-K contours.

The lower measurement limit for present photopyrometry systems is 1250 K, as mentioned above. This lower limit is determined to a large extent by the degree of infrared response of the image intensifier device. The image intensifiers presently used are state-of-the-art in this respect; the long-wavelength sensitivity limit is approximately 0.93 μm. Close liaison has been maintained with manufacturers and users of image intensifiers; it does not presently appear that there will be intensifier developments in the near future that would allow development of photopyrometers having measurement limits lower than the present ones.

An alternative surface temperature measurement approach, using infrared radiometer techniques, was pursued during FY80. A single-scan pyrometer using a high-speed, indium-antimonide infrared detector was designed and fabricated. The pyrometer, shown in Fig. 3, features liquid nitrogen cooling, an f/10 optical system, spectral response from 3.5 to 5 μm, and a rise time of 20 nsec. Output recording is accomplished using a Nicolet Explorer II® transient recorder.

Experimental evaluations of the single-scan pyrometer, calibrated through use of a blackbody source, were performed in Track G. The pyrometer was used to record temperature information at the same axial location as one of the Track G photopyrometers (Station IC-20). The experimental single-scan pyrometer was arranged to "view" the test model (Fig. 2) at an angle of 30 deg from head-on; the photopyrometer was used in its standard arrangement, viewing at 5 deg from head-on. The field of view or "scanning spot" of the experimental pyrometer was 0.1 in. in diameter.

Data recorded by the single-scan infrared pyrometer are shown in Fig. 4. These data were recorded simultaneously with the photopyrometer data shown in Fig. 1. In Fig. 4, brightness temperatures are plotted along the ordinate; the origin of the distance scale along the abscissa is arbitrary. Correspondence of the temperature measurements with the test model features is as indicated below the temperature plot. A very encouraging aspect of the data of Fig. 4 is that signal levels corresponding to brightness temperatures as low as 600 K can be recorded with a spatial resolution of 0.1 in. Also, the rise time of the pyrometer seems to be adequate for recording such extremely fast transient events.

The data of Fig. 4 point out some problem areas. Notice that a signal was received by the pyrometer before the nosetip actually came into the field of view. This occurrence is attributed to reflections off the track hardware; no provisions were made to provide a black background. Obviously, during future work, measures must be taken to minimize such reflections. In addition, the isothermal contour map (photopyrometer data) of Fig. 1 does not show any nosetip temperature higher than 2000 K, whereas the simultaneously recorded data of Fig. 4 indicate temperatures nearing 2500 K. This discrepancy is being investigated; calibration sources, calibration techniques, and extraneous radiation sources are among the possible causes under scrutiny.

Specifications were prepared and purchase arrangements were made for a three-element infrared detector linear array. FY81 work will include design, fabrication, and evaluation of a three-channel pyrometer that will provide three temperature scans across the nosetip of a test model in flight in Track G.

3.0 LASER PHOTOGRAPHY IMPROVEMENTS

Laser photography systems (Refs. 1, 3, 5, 6, and 7) were developed over ten years ago and have been used extensively in the VKF aero-ballistic ranges to provide stop-motion photographs of test models in hypervelocity flight. A schematic diagram of a laser photography system as applied in the Track G and Track K facilities is shown in Fig 5. Both frontlight and backlight beams derived from a pulsed ruby laser (6943-Å wavelength, 15-nsec pulse duration) illuminate the model as it passes the photographic station. The laser light enters and the camera views through slots in the track tube. Normally, the recording camera is filtered by a 100-Å bandpass (FWHM)* filter.

Most of the time, the laser photographic systems provide excellent stop-motion pictures as evidenced by Fig. 2 and by the sequence of Track G laser photographs shown in Fig. 6. However, some conditions are encountered in Track G where an overabundance of self-luminosity causes problems. The quality of photographs obtained with standard laser photographic systems during high-pressure (≥ one atmosphere) erosion and ablation tests in Track G is less than desirable. These tests are characterized by large quantities of model and wake radiation at or near the wavelength of the ruby laser (6943 Å). This background luminosity leads to extremely low-contrast photographs. An example of one of these low-contrast photographs is shown in Fig. 7. This test model was launched at 17,600 ft/sec into a range pressure of 1.2 atmospheres (910 torr). There is a high degree of uncertainty in nosetip recession data extracted from such low-contrast photographs.

Two approaches were made toward improving the quality of laser photographic results during high-ambient-pressure testing in Track G. First, a straightforward approach of using more narrow bandpass filters (< 100 Å) was pursued. An alternate approach, that of converting to a laser wavelength at which background radiation is not so severe, was also pursued.

An assortment of narrow bandpass optical filters was purchased. These filters have bandpasses more narrow than those normally used, with the most narrow of the assortment having a bandpass of only 3 Å (FWHM). No high-pressure tests have been conducted in Track G since purchase of the filter assortment; however, an opportunity for evaluating the use of the narrow band filters to alleviate self-luminosity problems did arise when a problem was encountered during testing of some gas-jet models in Track G. This type model was prone to lose significant portions of the heat shield material (see Fig. 2) during or shortly after launch, thereby exposing an aluminum undersurface and the remains of the bonding material. Ablation of the aluminum and/or bonding material produced a high level of red light. Laser photographs made under these conditions were characterized by large amounts of background exposure that seriously detracted from photographic contrast; Fig. 8 illustrates this problem. Several filters from the narrow-band assortment were tried in the laser photographic system that recorded this photograph. Test exposures made using 3-, 5-, and 10-Å-wide filters revealed that use of these filters with the present optical system was

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*Full width at one-half of the maximum transmission value.

not practical because of severe viewfield restrictions and low transmission values. However, a 30-Å-wide filter was found to work quite well. The laser photography system with 30-Å-wide filter was used during subsequent shots of gas-jet models. A marked improvement in photographic quality was achieved, as evidenced by Fig. 9. This test model, like the one pictured in Fig. 8, had lost its heat shield; velocity and pressure conditions were the same.

It is planned to continue evaluation of narrow band filtering techniques during high-pressure tests scheduled for FY81. Laboratory experiments have shown that filters with bandpasses as narrow as 15 Å may be used with present laser photographic system arrangements. Certainly, use of 15- or 30-Å-wide filters will provide some measure of improvement in laser photography at high-pressure conditions; the degree of improvement remains to be determined.

The background luminosity associated with high-pressure, Track G shots is known to be more intense in the red (long-wavelength) spectral region than it is in the blue (short-wavelength) region. The possibility of converting to a blue-green laser wavelength, at which background radiation is not so severe, was investigated. It was found that components are available for converting existing Holobeam lasers to operate at a wavelength of 5300 Å (blue-green). Substitution of a neodymium laser rod (1.06-μm wavelength) and employment of a frequency-doubler device are required. An appropriate neodymium rod and frequency doubler were specified and placed on order. When these components are available, one of the Holobeam lasers will be modified and evaluated in a Track G laser photography system.

4.0 TIME-RESOLVED SPECTROMETER

It is of interest to spectrally characterize specific portions of hypervelocity impact phenomena such as the initial impact flash (Fig. 10), the luminous debris cloud ejected from the rear of a target (Fig. 11), and the collisions of debris clouds with second and third targets. To obtain separate spectral measurements of these sequential events, which may persist for only a few microseconds (e.g., see Fig. 10), requires a spectrometer that can be gated on for only the time period of interest.

A spectrometer that provides the required time resolution was designed and fabricated using a small spectrograph and an image intensifier camera. A schematic diagram of the spectrometer is shown in Fig. 12. Spectral lines produced by the spectrograph grating are intensified and recorded by the gatable image intensifier. The device can be gated on for periods as short as 100 nsec. The spectrometer uses a 600 line/mm grating and has a dispersion of 100 Å/mm; spectral resolution is estimated to be ±30 Å. The 2200-Å-wide bandpass of the system can be shifted as desired within a 3500- to 6800-Å overall wavelength band.

The intensified spectra are recorded on photographic film. The spectrometer is not calibrated for absolute intensity measurement but is wavelength calibrated using a mercury vapor light source. A densitometer is used to read photographic density of spectral lines on the film. A computer program that takes intensifier and film response characteristics into account transforms film density values into relative intensities.

To date, only laboratory evaluations of the spectrometer have been performed. No impact tests have been performed in the VKF ranges since completion of the device. It is hoped that thorough evaluations can be made during FY81 impact tests in Range S1.

5.0 X-RAY MODEL DETECTION SYSTEM

Most instrumentation systems, especially those that are photographic in nature, require a means for precisely detecting and annunciating the arrival of a model at a particular photographic or measurement station; i.e., a properly timed trigger pulse must be provided to activate the instrumentation system. The track facilities, wherein the test model is confined to a straight-line trajectory, allow a simple optical barrier technique (Ref. 2) to be applied. In this simple technique, the beam from a continuous-wave laser (He-Ne) is directed across the centerline of the track to a detector on the other side. A trigger pulse is derived from the detector when a model in "flight" on the track interrupts the laser beam.

The cw laser detection technique works quite well for most applications in Tracks G and K. There is one particular area, however, where the reliability of the technique is less than desirable. An orthogonal, X-ray shadowgraph system (Ref. 5) is used in the blast-tank area of Track G to record photographs (radiograms) of the model a few feet from the muzzle of the launcher. Such photographs are important for examinations of the structural integrity of models near the beginning of "flight." They are especially important as a diagnostic aid in the event of a major model or nosetip failure during launch. The reliability of the cw laser detection system for providing a properly timed trigger for this X-ray shadowgraph (designated "A" Station) is only 40 percent for good, "clean" model launches. As for cases where there is a major model/nosetip failure (and the photographic information would greatly aid diagnostic efforts), proper triggering is achieved during only about 5 percent of such instances.

Some of the known causes for failure of the "A" Station cw laser detection system include high ambient luminosity, particles preceding the model, and turbulent or smoke-like gases in front of the model. As would be expected, a very bright muzzle flash is produced by the large Track G launcher. This light, high in red content, can sometimes bias the detector "on" even after the laser beam is broken by the model. This is probably the predominant failure mode on good launches and usually results in a "late" trigger.

When a nosetip fails (e.g., shatters to some extent) during launch, particles from the nosetip are likely to cross the laser beam ahead of the model. Since the laser beam is only about 3 mm in diameter, fairly small particles or groups of particles can attenuate the laser beam and lead to "early" triggers.

When there is a major failure of the plastic base section of the model (the cylindrical part that conforms to the bore of the gun), the driving gases can "blow by" the model. These fast-moving, turbulent and/or smoky gases reach the laser beam before the model and cause an early trigger by deflection and/or attenuation of the beam. "Blow-by" sufficient to cause improper triggering can occur sometimes without catastrophic failure of the model base; i.e., it can occur on otherwise good launches.

A noninterfering detection system for use in the Track G muzzle zone was designed around a continuous-wave X-ray source and a scintillation detector. It was reasoned that an X-ray/scintillation detector system, identical in principle to the cw laser detection system discussed above, would be practically impervious to the conditions that cause failures of the laser-light system. The scintillation detector will not respond to the visible light of the muzzle flash; the X-ray beam will not be deflected or attenuated by turbulent or smoky gas streams, and since the X-rays will pass through small particles with very little attenuation (and the X-ray beam will be considerably larger than the laser beam), it was surmised that only a model or a significant "chunk" of a model is likely to be detected by such a system.

A 100-kV, constant-potential X-ray source and a fast-response scintillation detector were used to fabricate a model detector for the "A" Station X-ray shadowgraph. A schematic diagram of the setup is shown in Fig. 13. The centerline of the detector system is only 54 inches from the muzzle of the launcher. The portion of the cw X-ray beam intercepted by the scintillation detector is approximately 1 in. in diameter at the center of the track. (The laser beam was 3 mm or approximately 1/8 in. in diameter.) The source and detector are mounted on floor stands (rather than attached to the tank wall) to minimize vibration problems. A delay generator is used to delay (and condition) the trigger signal until the model reaches the center of the X-ray shadowgraph station.

The cw X-ray detector system has been used to trigger "A" Station during the last 40 shots in Track G. Thus far, the detector has been 100 percent reliable. A photograph of a typical output waveform from the scintillation detector is shown in Fig. 14. Prior to arrival of the model, the detector exhibits a "constant" negative output. As the model passes through the beam, a positive going pulse, reaching zero (horizontal cursor) at its peak, is produced. The width of the pulse corresponds to the time required for the model to travel through the X-ray beam. The detector output then returns to its "constant" negative level until the "A" Station X-ray pulser fires (vertical cursor) at a programmed 115-μsec delay from model detection. Scattered radiation from the X-ray flash drives the detector further negative to a saturated condition (flat bottom). Eventually, the detector output returns to the "constant" level.

Some photographic results achieved with the "A" Station orthogonal X-ray shadowgraph system are shown in Fig. 15. Figure 15a depicts a good launch; Fig. 15b shows a model with slight nosetip damage (notice particles in horizontal view); Fig. 15c show a model with major nosetip damage; and Fig. 15d shows catastrophic failure of a model. Most of these important photographs could not have been recorded without use of the highly successful cw X-ray detector system.

6.0 VARIABLE DURATION LIGHT SOURCE

A study was made of all the high-speed photographic impact data recorded last year (FY79). An example is shown in Fig. 16. Here the target is a canister-type device. This sequence was recorded by a Beckman & Whitley (B&W) Model 192 framing camera as it viewed through the target canister. After such data had been studied, it was concluded that significant improvement could be achieved by obtaining a better light source for use with the B&W camera.

The B&W is a continuous access camera. A light source must be provided that is "on" only for the period of time it takes for the camera to record its 80 frames; if the light stays on for a longer time period, rewriting (exposure of frames on top of previously recorded frames) occurs. The required light duration is a function of the framing rate being used. In previous work, a home-made light source was used. When a change in the framing rate of the camera was desired, it was necessary to make appropriate changes to the light source circuitry. An appropriate capacitance value had to be calculated, and the proper combination of available capacitors had to be determined and incorporated into the circuit. Often, it was impossible to achieve the desired flash duration and, in these cases, several frames of information were not usable because of rewrite or underexposure (not exposing all 80 frames).

A commercially available light source, developed specifically for use with high-speed cameras, was purchased. A photograph of the light source and a listing of some of its specifications are presented in Fig. 17. The source is specified to have a 10-μsec risetime. The fall time is also near 10 μsec so that the source provides a good approximation of a square-wave light pulse. The range over which the duration can be varied (40 to 625 μsec) will allow convenient use of the full framing-rate capability of the B&W camera; i.e., any framing rate between about 400,000 and 1,500,000 frames per second can be selected, and the appropriate light duration can simply be dialed in.

The light source was acceptance-tested in the laboratory but has not been used with the B&W camera, since no impact tests have been performed since receipt of the new light source.

7.0 CONCLUDING REMARKS

Experimental results with the prototype, single-scan infrared pyrometer are very promising. It appears that this infrared-detector technique can be applied to measure in-flight nosetip temperatures as low as 600 K. Discrepancies of a few hundred degrees between measurements with the single-scan pyrometer and a conventional photopyrometer system must be resolved. A problem area, possibly associated with reflections off track hardware, was identified and must be solved during further work on a three-channel, infrared pyrometer.

Narrow bandpass filtering techniques were found to improve the quality of laser photographs during gas-jet model tests characterized by high background luminosity levels. It remains to be seen how much these techniques will enhance laser photography during future, high-pressure, ablation and erosion tests in Track G. As another approach to the high-luminosity problem, laser photography using a blue-green laser wavelength of 5300 Å (a wavelength of 6943 Å is presently used) will be evaluated in the future.

Experimental evaluations of two instrumentation systems are awaiting the scheduling of a suitable impact test in one of the VKF ranges. The time-resolved spectrometer and the new light source for the B&W high-speed framing camera have been evaluated successfully in the laboratory, but final assessments of the systems must be made during actual impact testing.

A cw X-ray detection system, located just 54 inches from the Track G launcher muzzle, has provided a 100-percent reliable trigger for "A" Station X-ray shadowgraphs on 40 consecutive shots. The reliability for correctly triggering this photographic station using cw laser detection techniques was only 40 percent for good launches and no more than 5 percent for cases where the model suffered damage during the launch process; reliability was inversely related to the value of the photographic information. Development of the new, highly reliable detection triggering system for the muzzle-zone X-ray shadowgraph has, for all practical purposes, added a new diagnostic instrumentation system to Track G.

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Model Velocity: 17,600 ft/sec
Viewing Angle: 5 deg from Head-On

Legend
Contour Intervals: 100 K
Heavier Lines Are 2000-K Isotherms

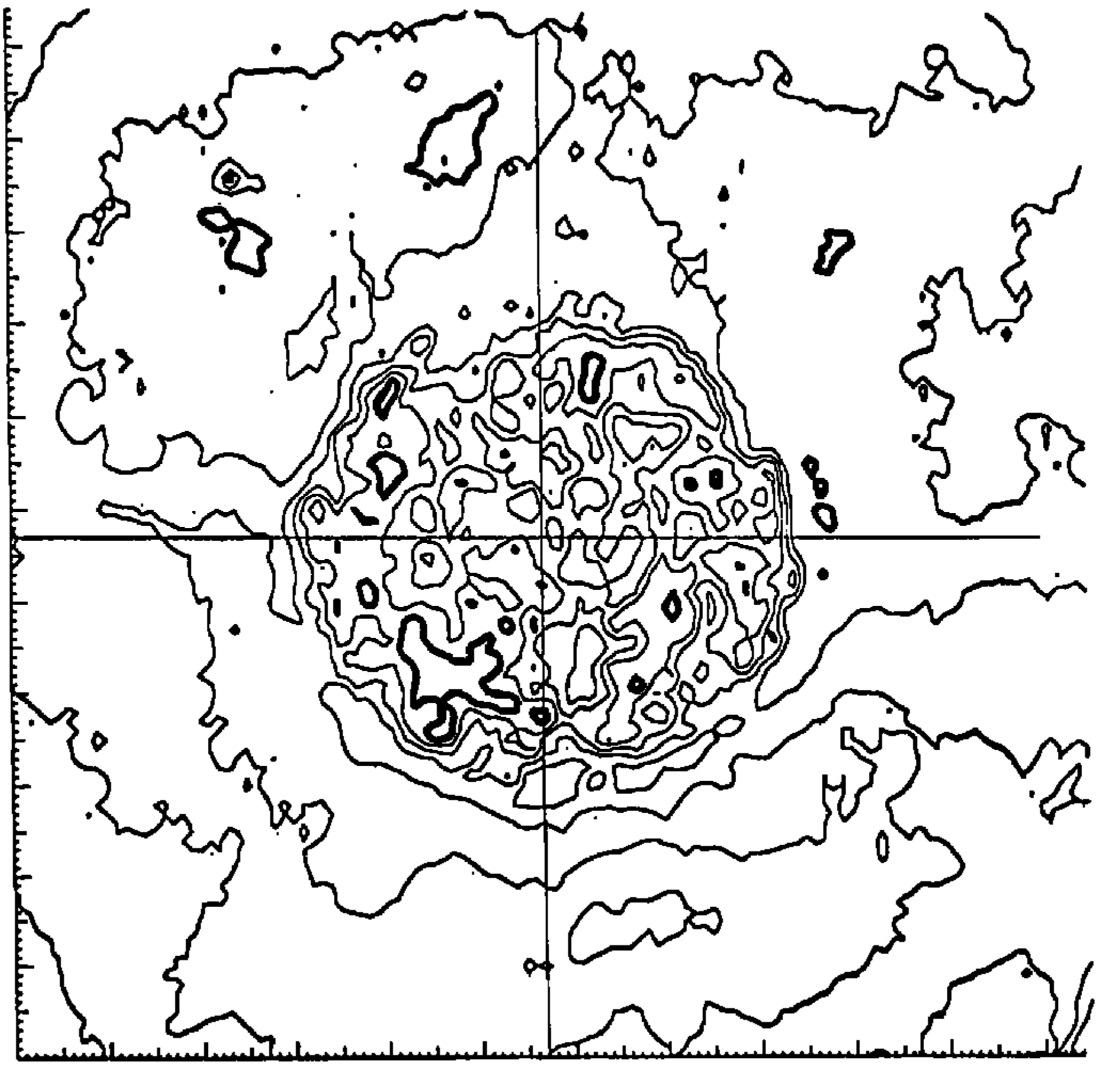


Figure 1. Isothermal contour map of photopyrometer data.

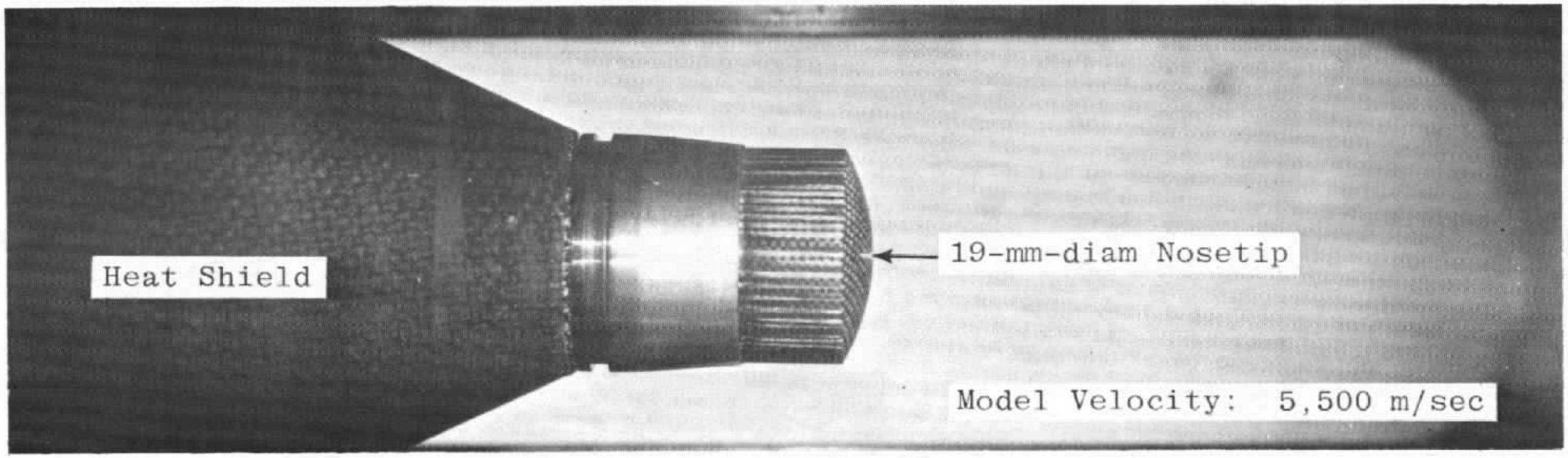


Figure 2. Laser photograph of ablation/erosion model in flight in Track G.

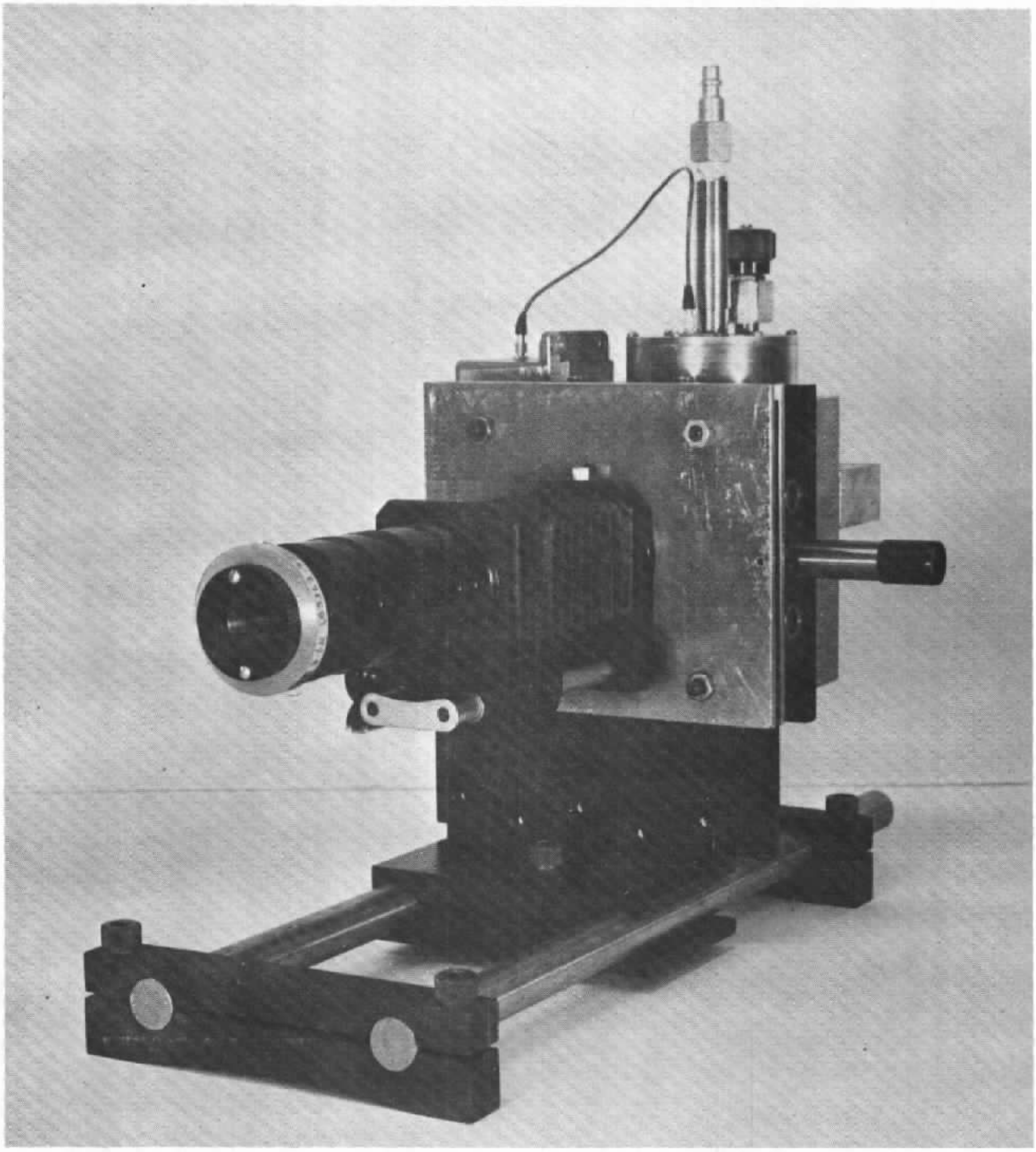


Figure 3. Single-scan infrared pyrometer.

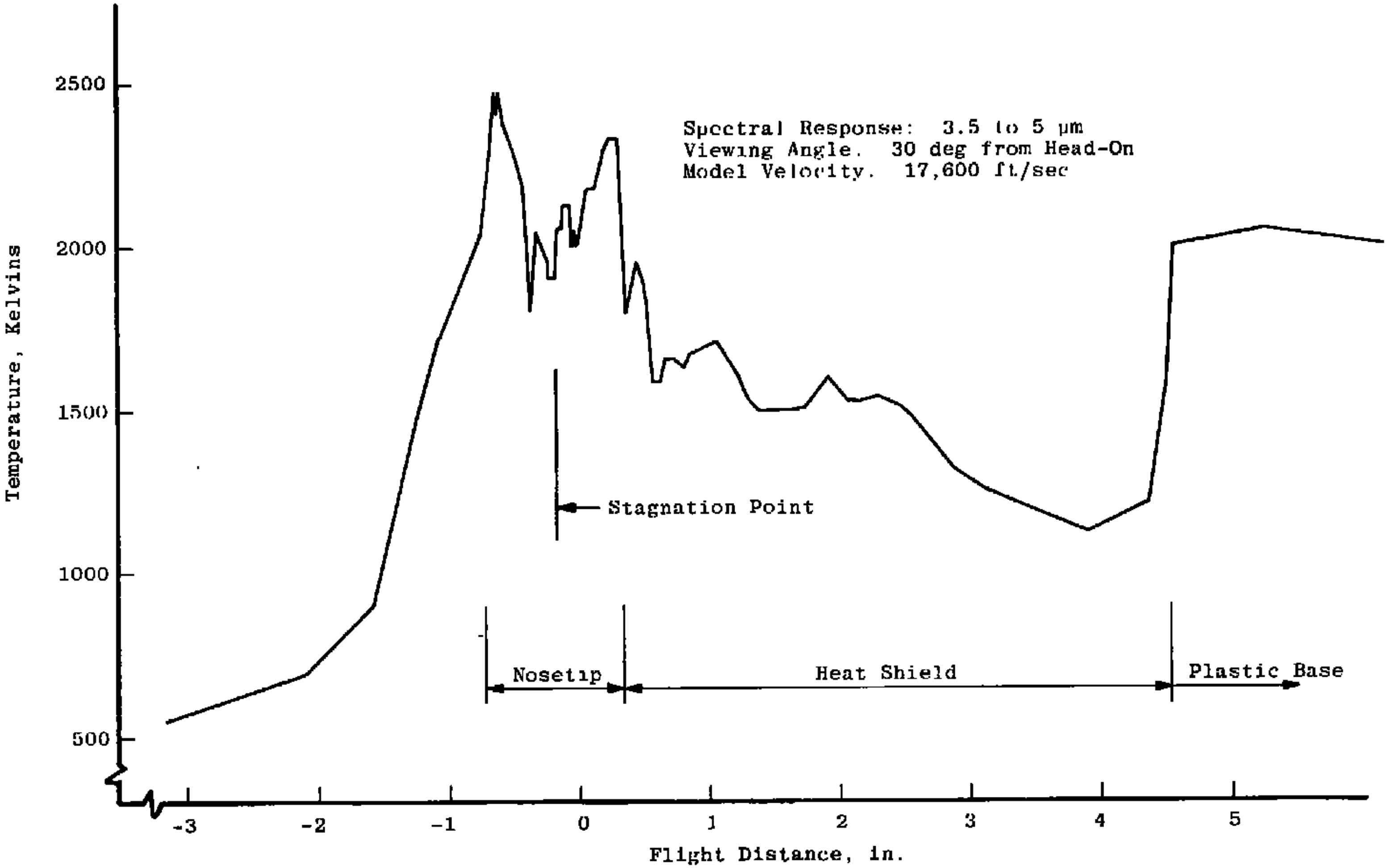


Figure 4. Single-scan infrared pyrometer data: shot 5350.

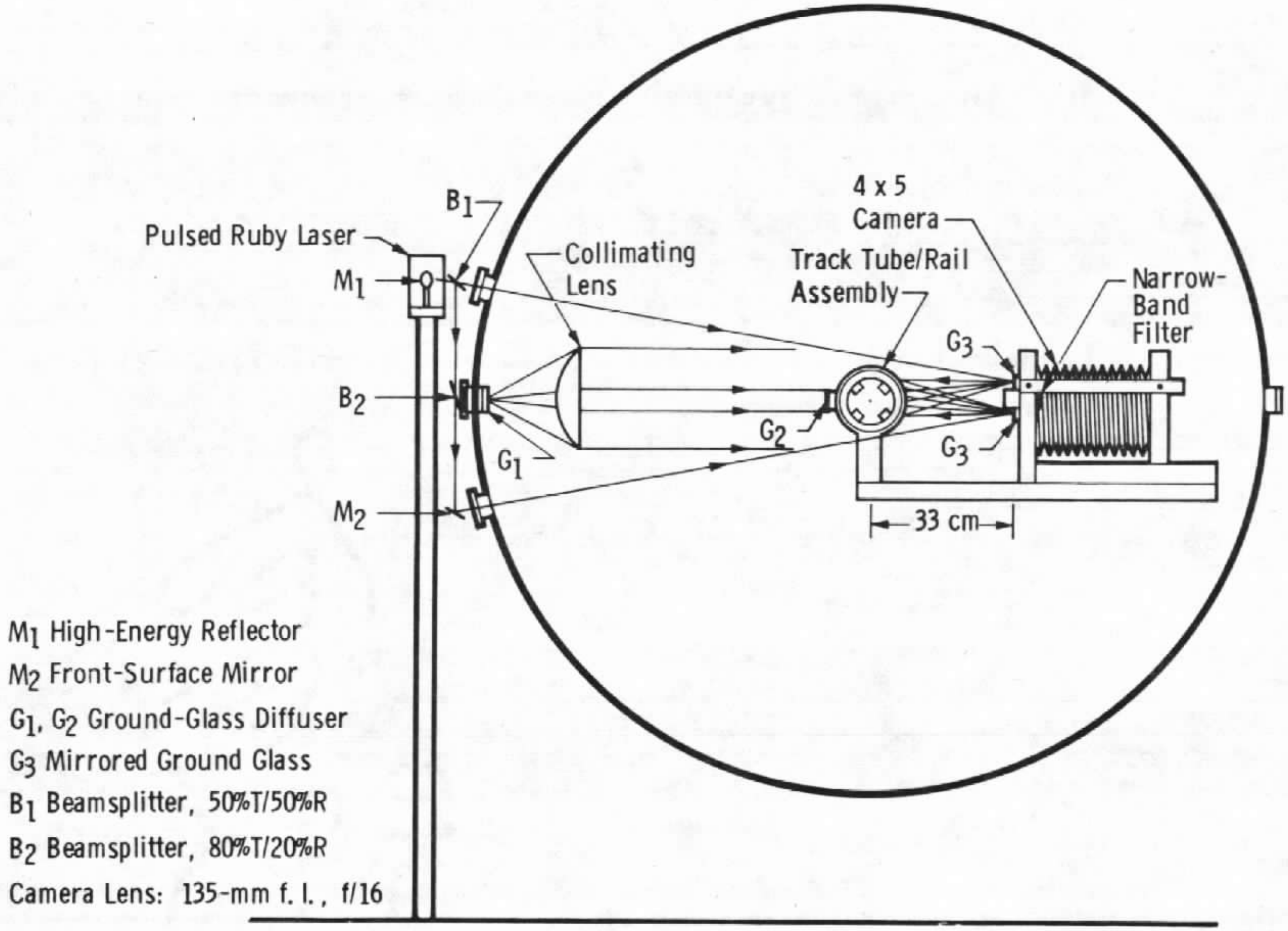
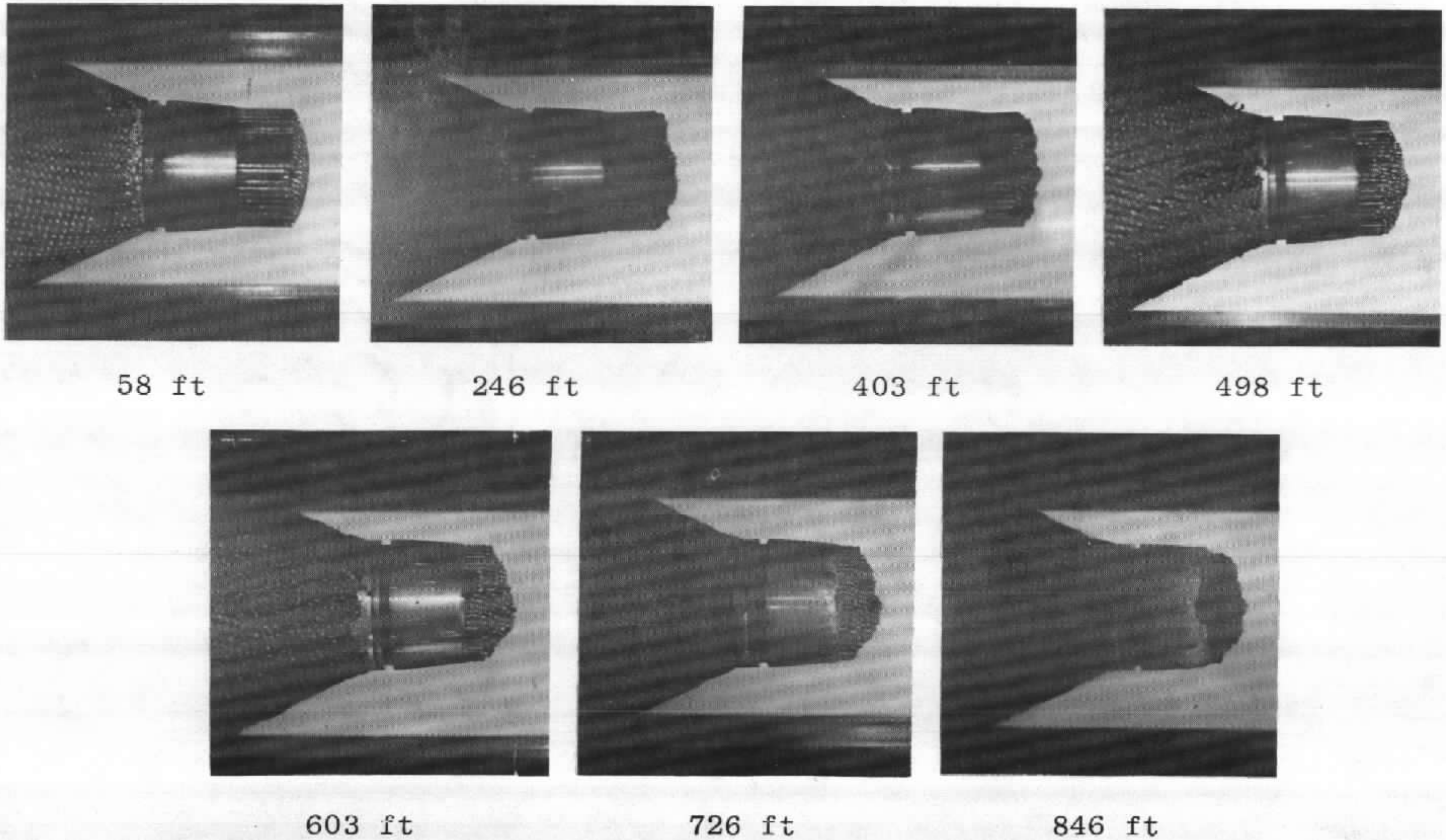


Figure 5. Track frontlight/backlight laser photography system.



Note: Flight distances are referenced to range entrance.

Figure 6. Sequence of photographs from Track G frontlight/backlight laser photography systems.

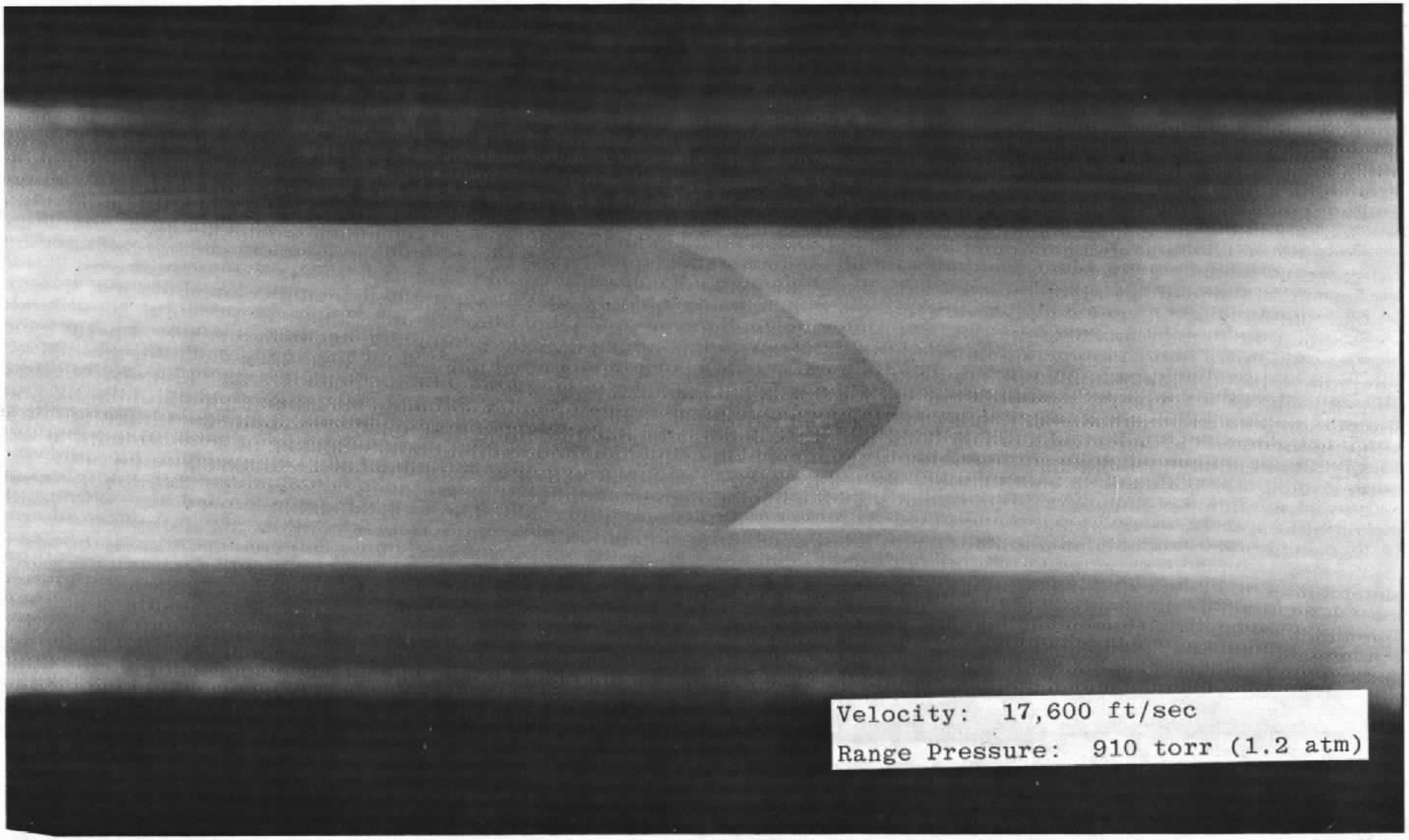


Figure 7. Frontlight/backlight laser photograph recorded during high-pressure ablation shot in Track G.

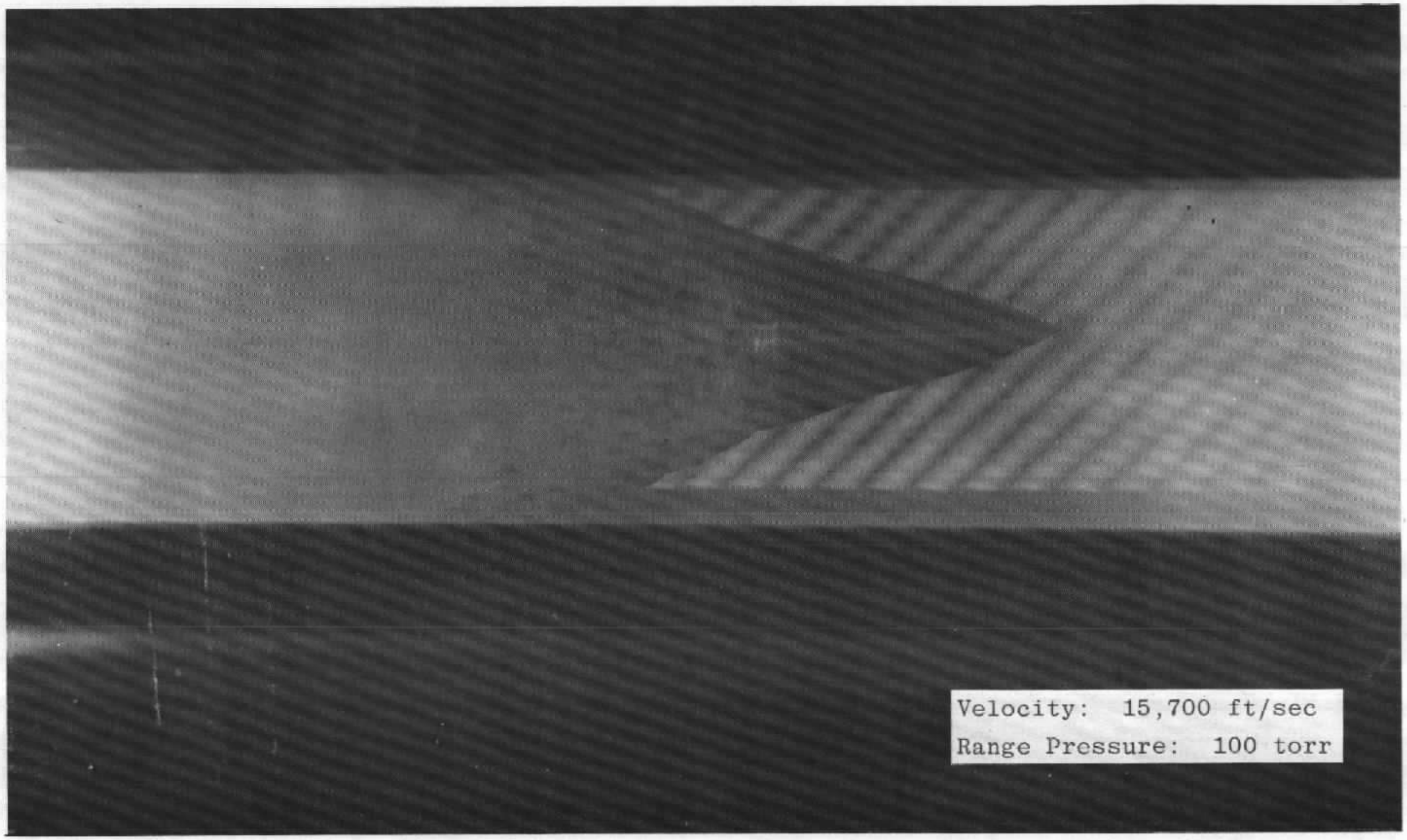


Figure 8. Laser photograph of gas jet model: standard 100-Å-wide bandpass filter used in recording camera.

Figure 9. Laser photograph of gas jet model: 30-Å-wide bandpass filter used in recording camera.

Flight Direction →

Model Velocity: 22,600 ft/sec
Framing Rate: 1,160,000 sec^{-1}
Exposure Time per Frame: 0.22 μsec

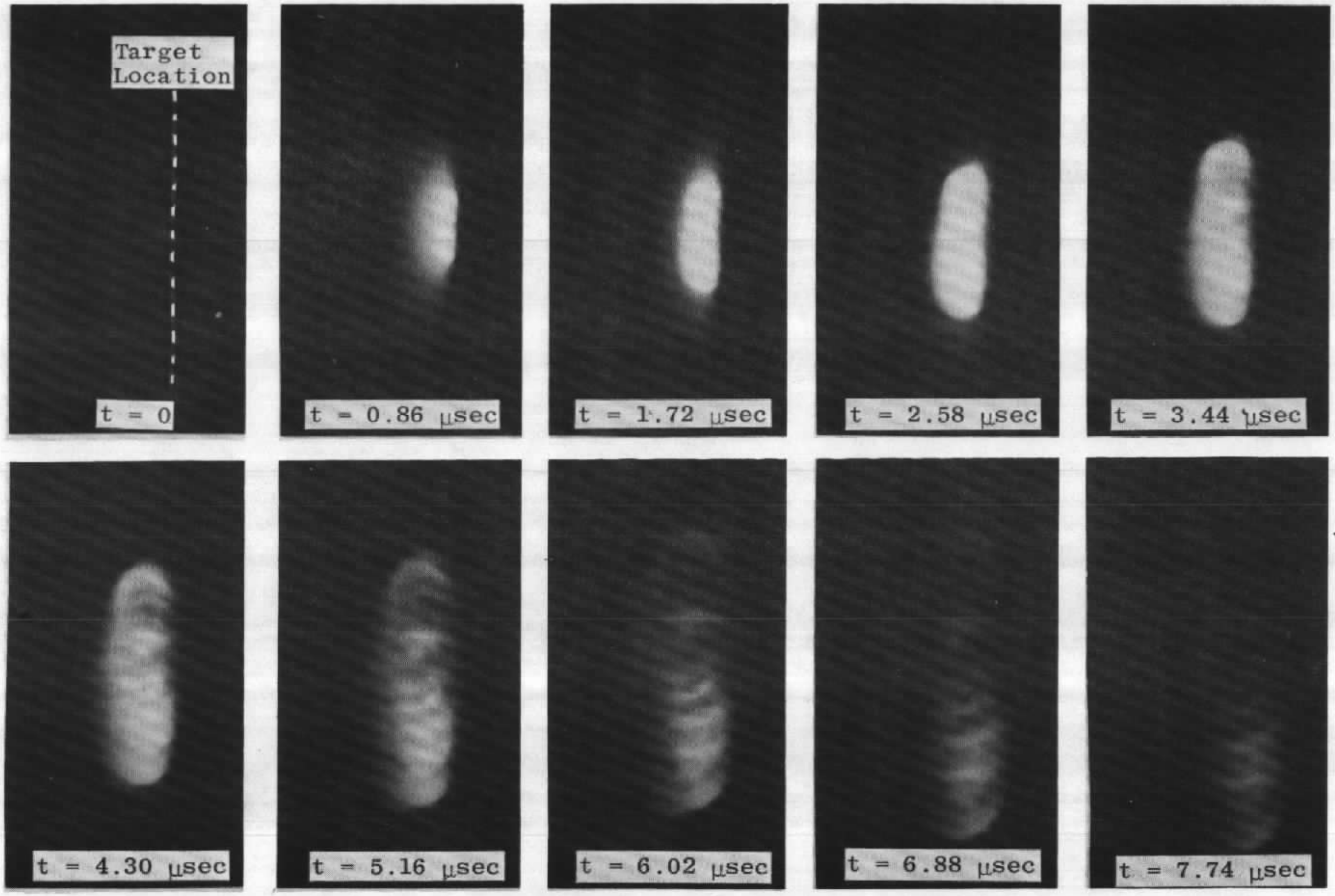
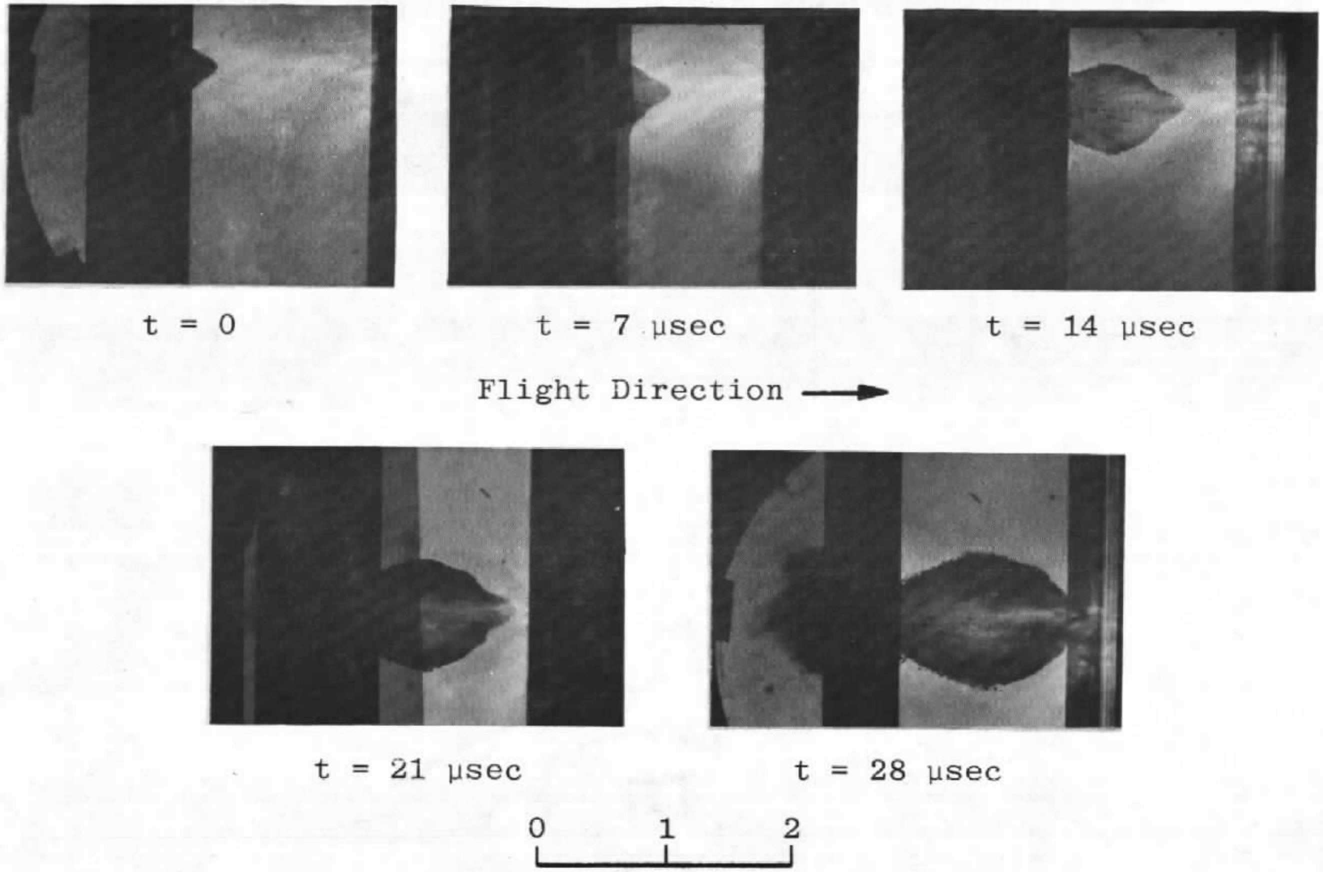


Figure 10. High-speed framing camera photographs of impact flash.



Note: The actual target thickness cannot be seen in these photographs; the target support frames are silhouetted in these edge-on views.

Figure 11. Sequential laser photograph of a debris cloud formed by hypervelocity impact with a first target progressing toward and striking a second target.

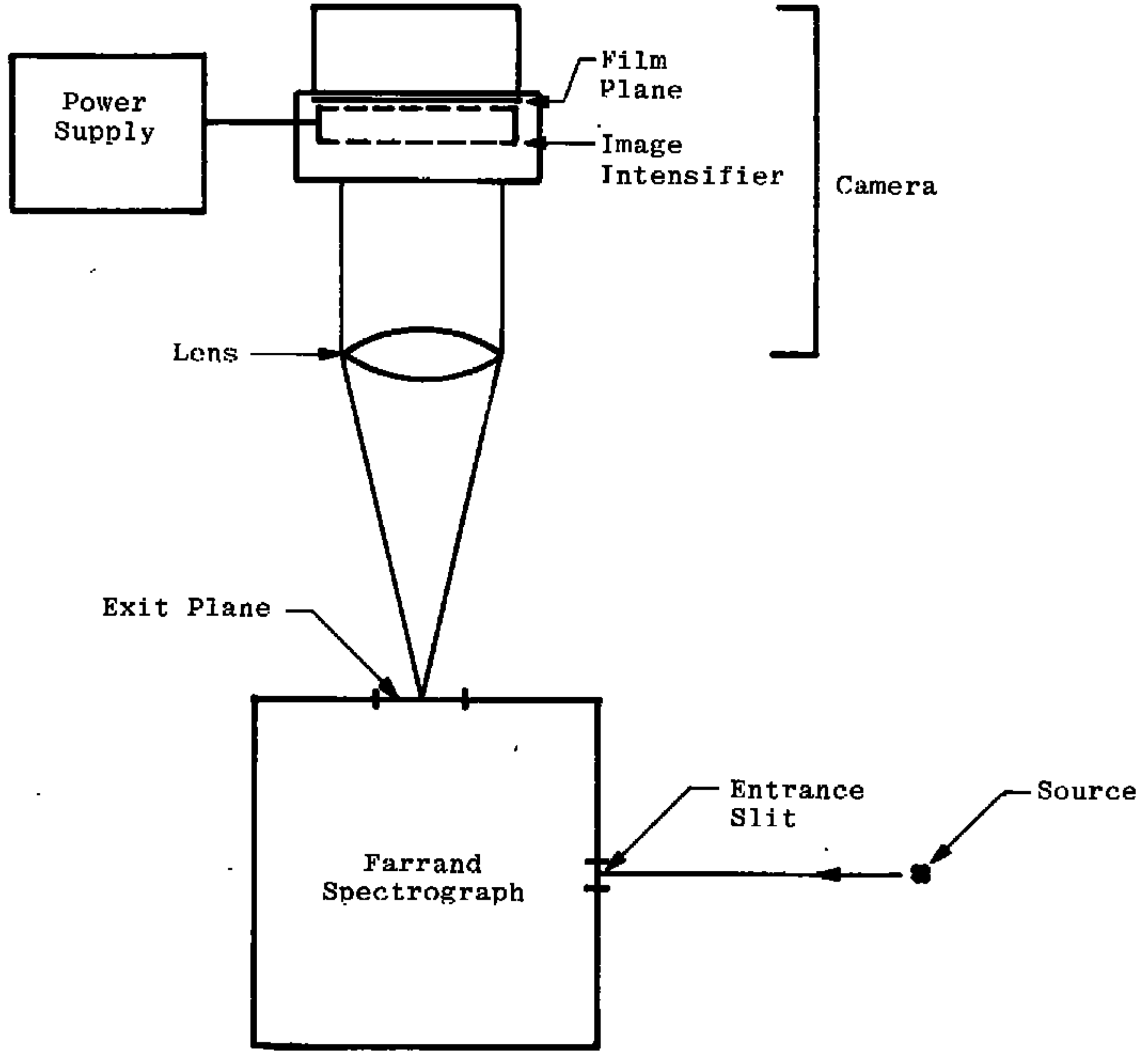


Figure 12. Spectrometer for impact studies.

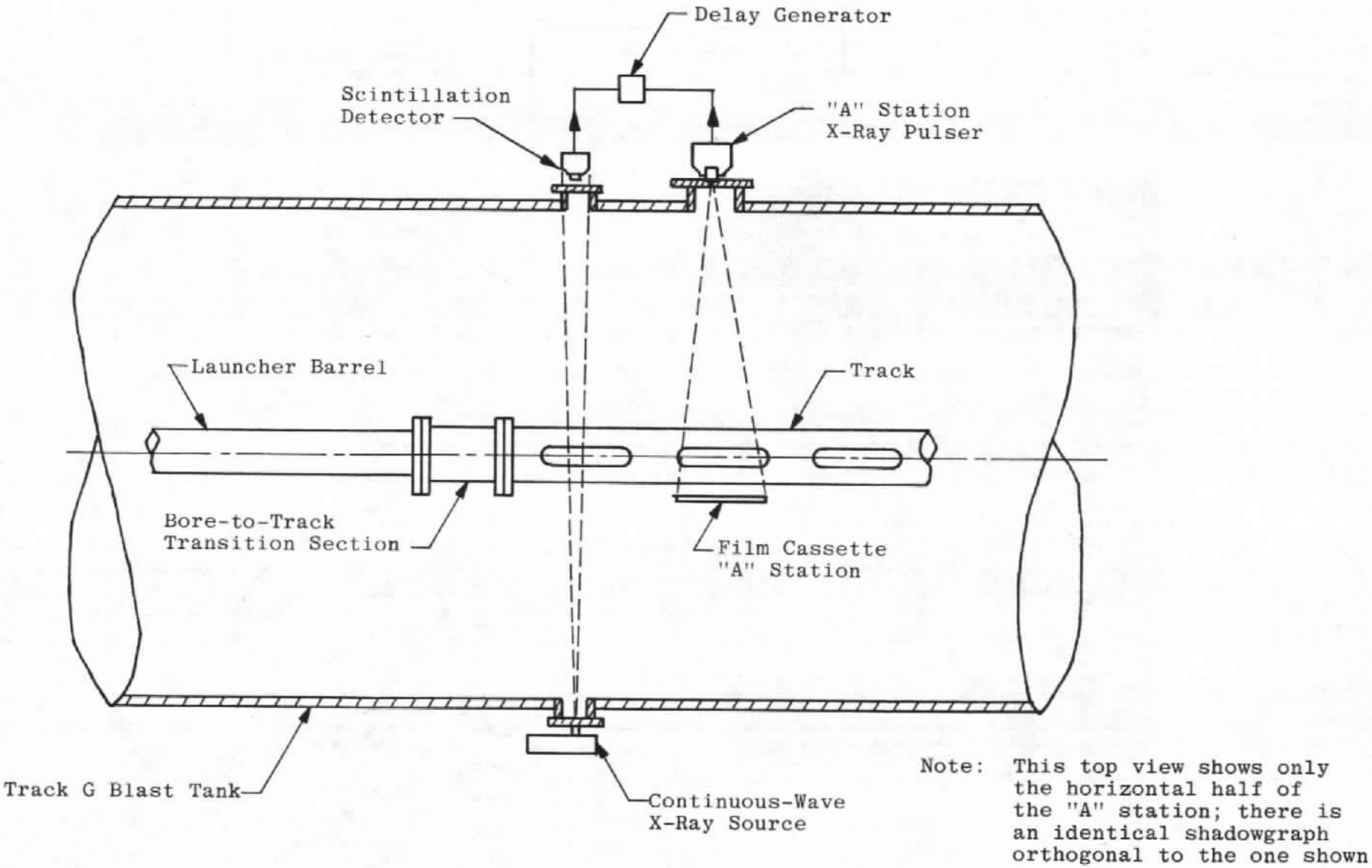


Figure 13. CW X-ray detection system for "A" station X-ray shadowgraph.

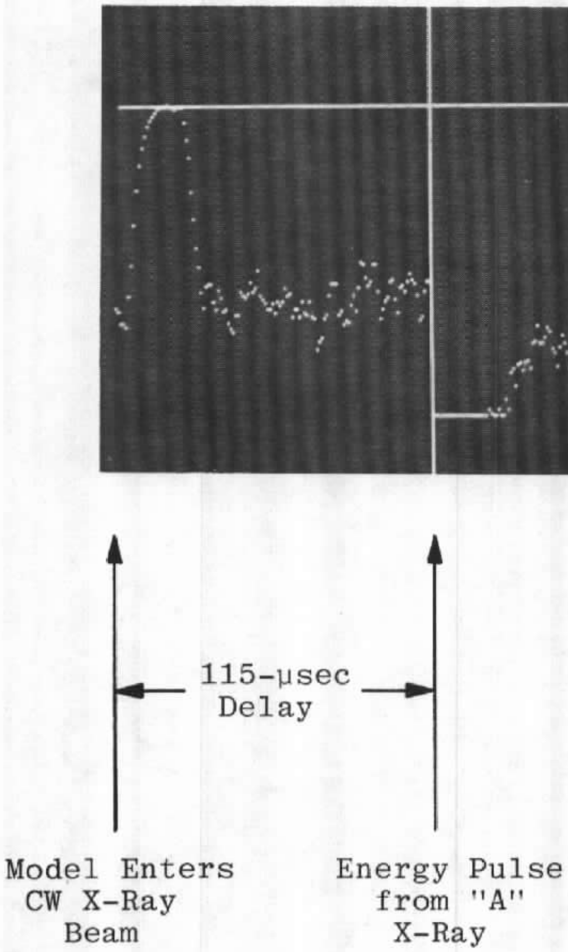
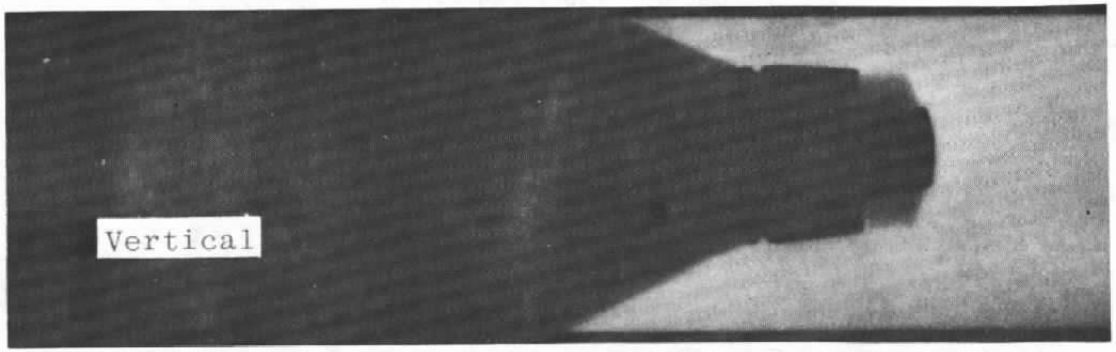
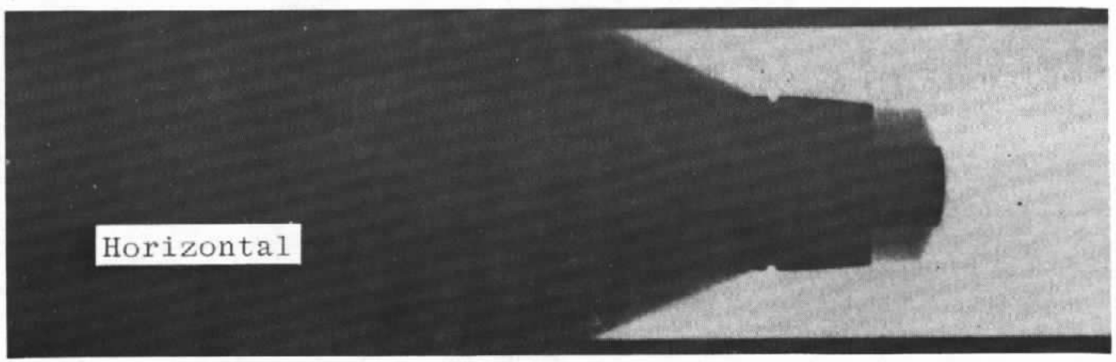


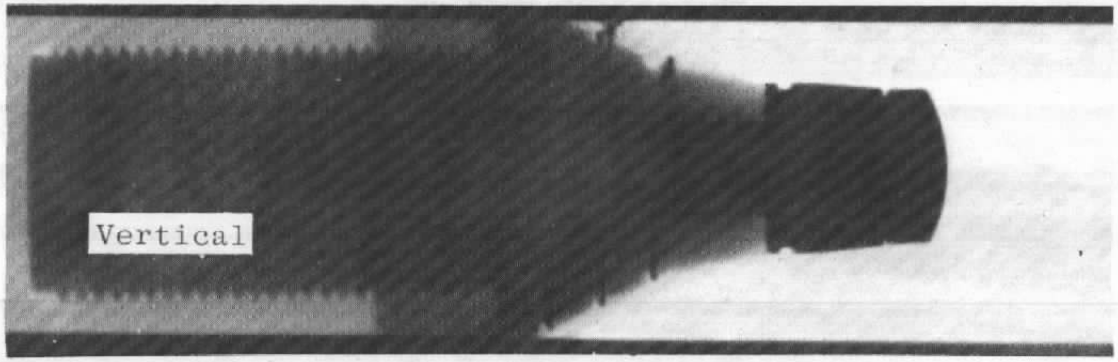
Figure 14. Scintillation detector output waveform.



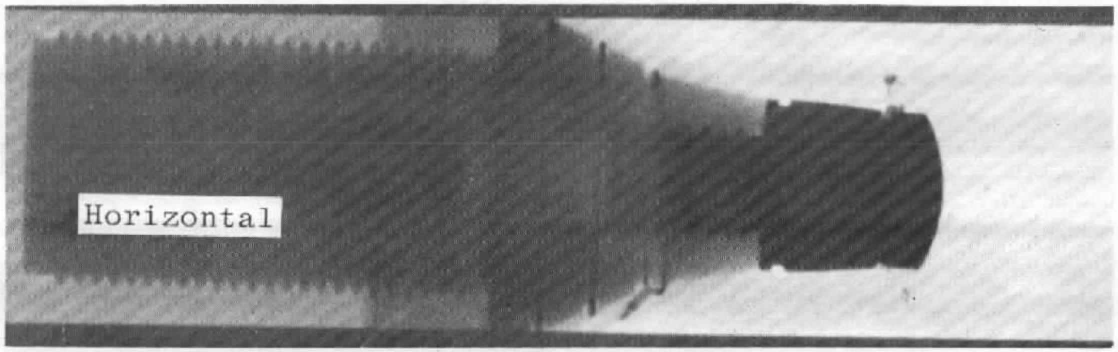
Model Velocity: 17,700 ft/sec



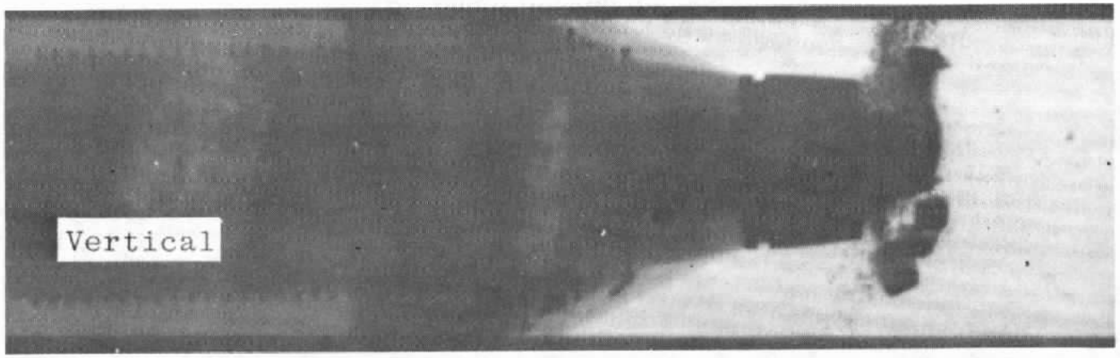
a. Undamaged model.
Figure 15. Muzzle-zone X-ray shadowgrams: "A" station.



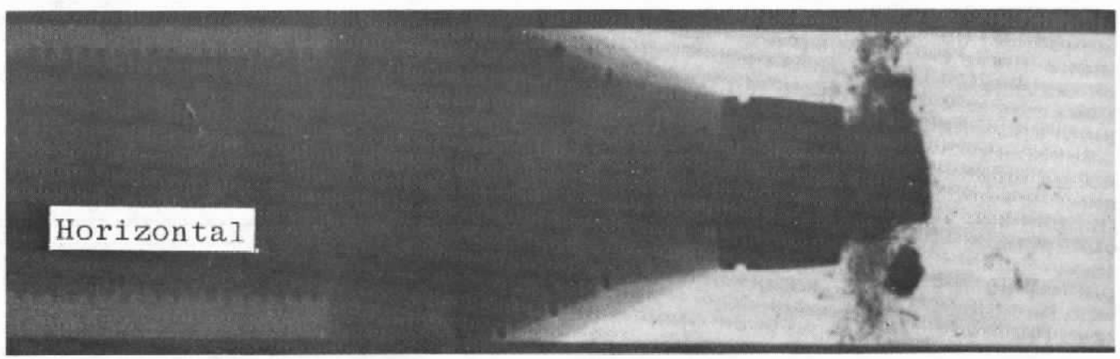
Model Velocity: 17,400 ft/sec



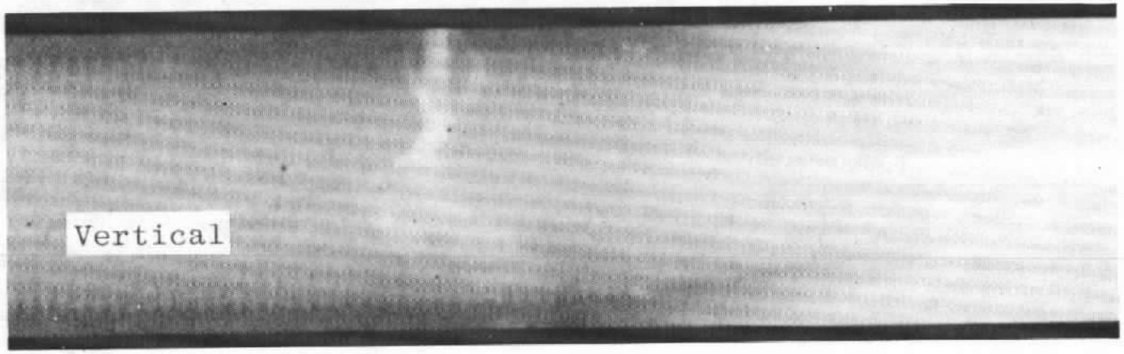
b. Slight nosetip damage.
Figure 15. Continued.



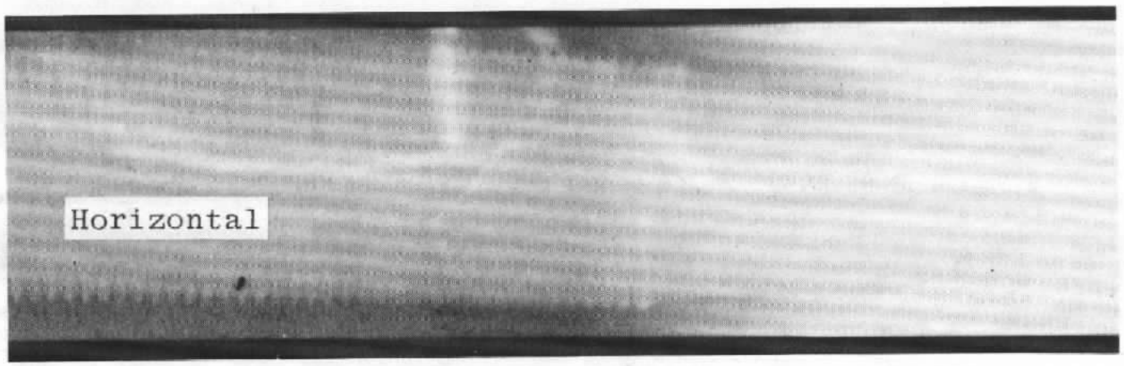
Model Velocity: 17,600 ft/sec



c. Major nosetip damage.
Figure 15. Continued.



Model Velocity: 17,700 ft/sec



d. Castastrophic model failure.
Figure 15. Concluded.

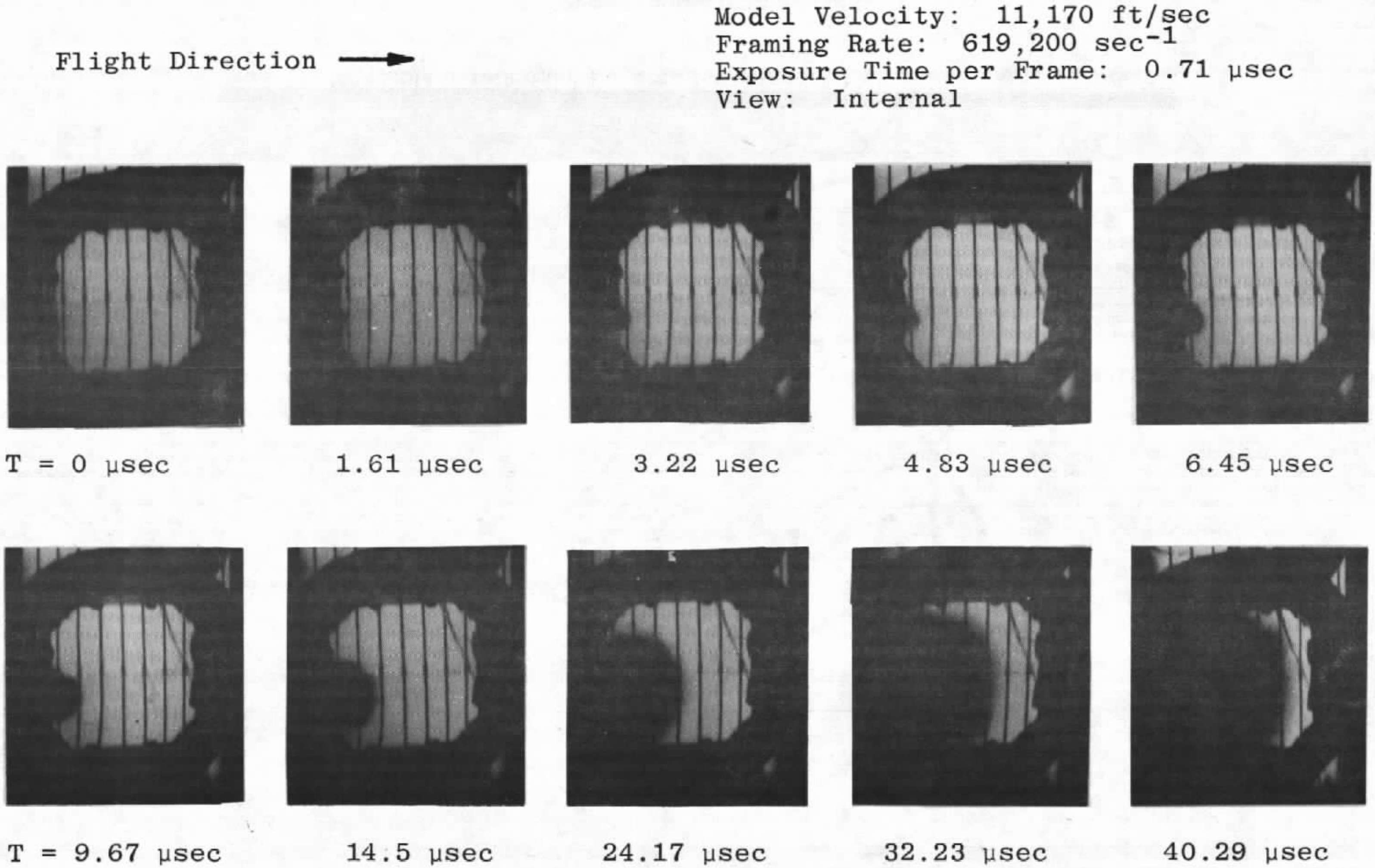
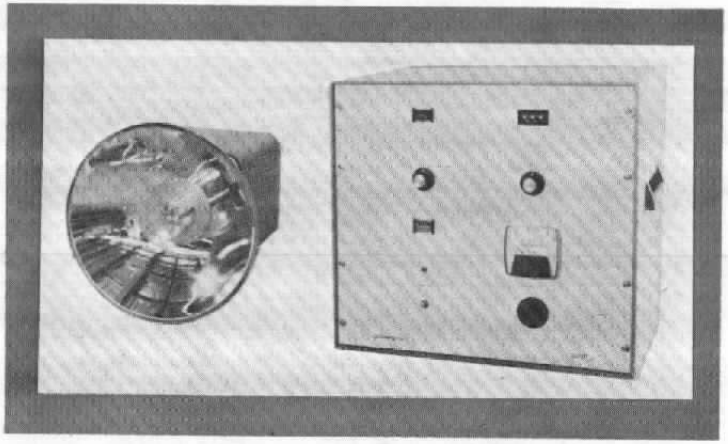


Figure 16. Backlighted high-speed framing camera photographs of MV target impact.

FEATURES

- Adjustable Pulse Duration
- Low Intensity Repetitive Mode for Alignment
- Remote Operation



SPECIFICATIONS

Flash Tube and Light Output:	Helical Xenon, 2400 Horizontal Beam Candlepower Seconds, Nominal
Light Pulse Width:	40 to 625 Microseconds (Direct Reading Digital Setting Variable in Steps of 1 Microsecond)
Rise Time:	Less Than 10 Microseconds (10 to 90 percent)
Trigger Input:	20 to 100 Volts with Rise Time Less Than 2 Microseconds
High Voltage:	2 to 5 KVDC, Continuously Adjustable
Power Requirements:	115 VAC, 60 Hz (220 to 240 VAC 50 Hz Available)
Cable Lengths:	Remote Flash Head to Control Unit - Standard 12 ft Optional up to 30 ft

Figure 17. Variable duration light source for use with high-speed framing camera.